Wide Dynamic-Range Beam-Profile Instrumentation for a Beam-Halo Measurement: Description and Operation

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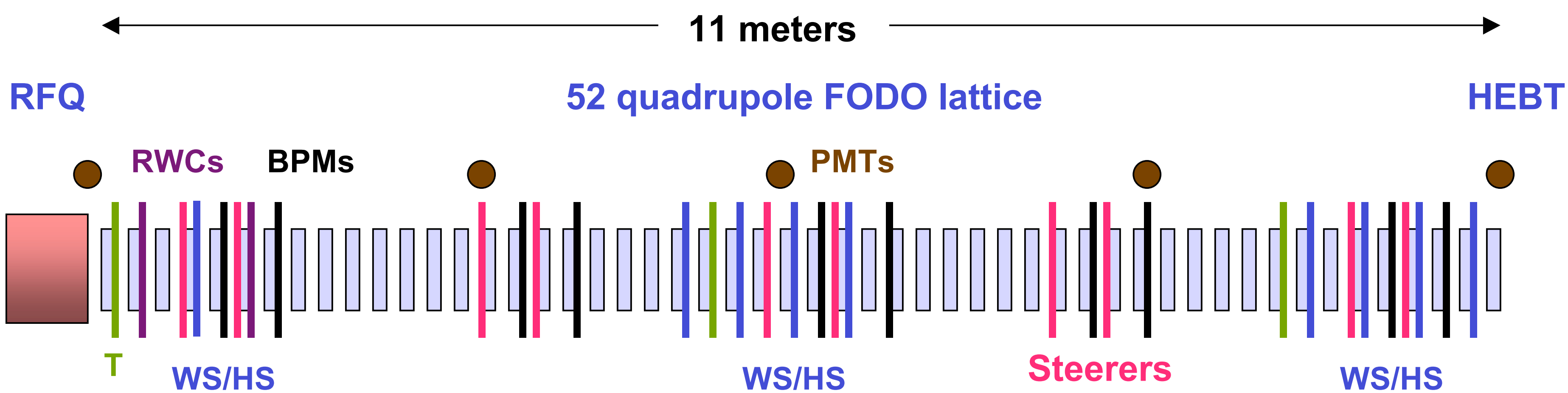
Outline

- Discuss experimental layout
- Describe projected distribution instrumentation
  - Basic wire scanner and halo scraper mechanism
  - Discuss wire- and scraper-beam interaction
  - Describe typical beam operation during data acquisition
  - Wire/scraper movement control and charge detection
  - Data analysis
  - Show typical data
- What we did right and lessons learned.
- Summary
- Relevant papers

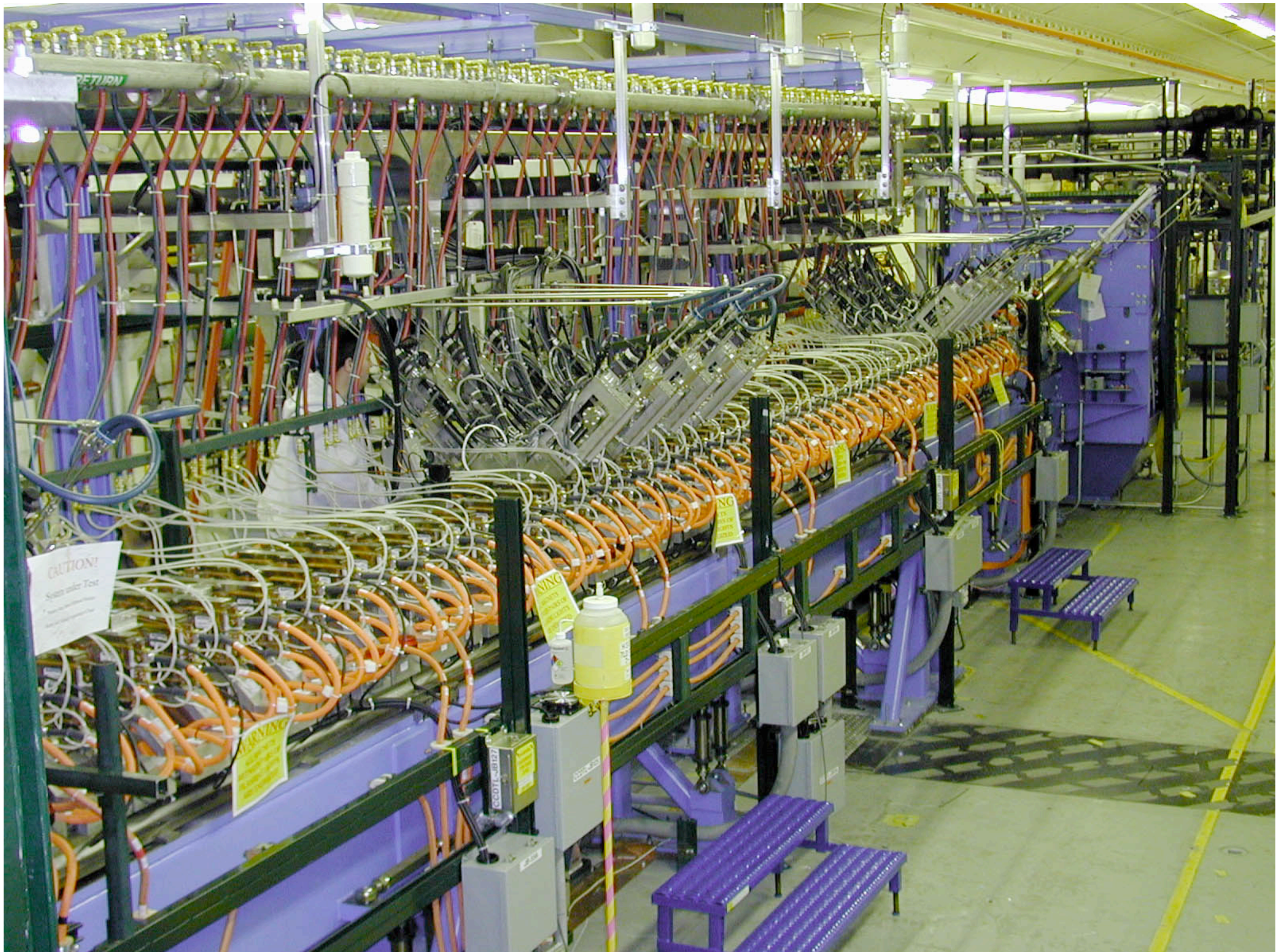
Fully Instrumented LEDA Beam-Halo Lattice



First 4 quadrupoles independently powered for generating mismatch modes.

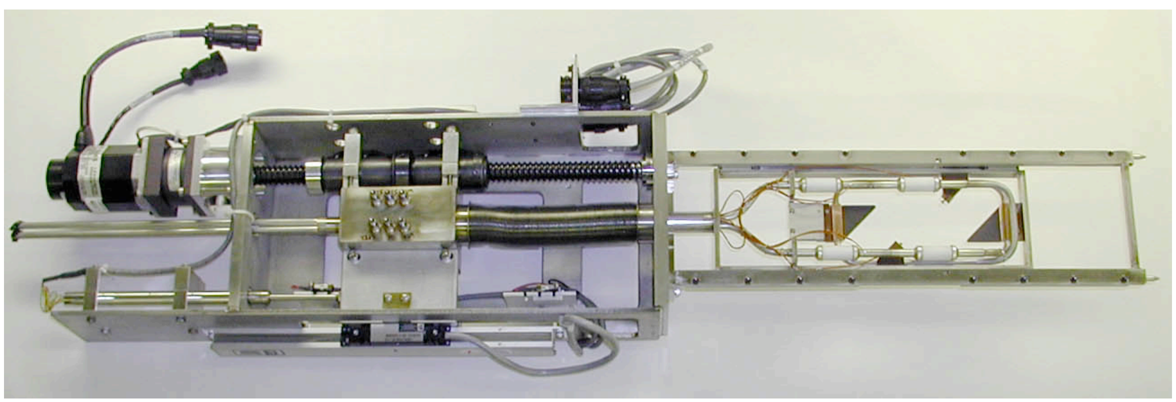
52 Quadrupoles + 4 in the HEBT
9 Wire Scanners/Halo Scrapers (Projections) + 1 in the HEBT
3 Toroid (Pulsed Current) + 2 in the HEBT
5 PMT Loss Monitors (Loss) + 2 in the HEBT
10 Steering Magnets + 2 in the HEBT
10 Beam Position Monitors (Position) + 5 in the HEBT
2 Resistive Wall Current Monitors (Central Energy)

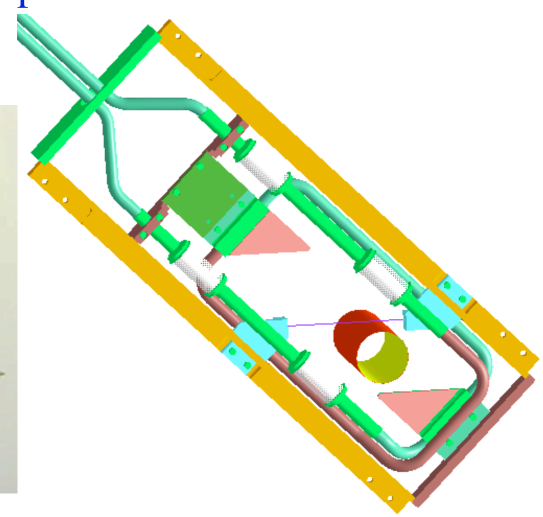
LEDA Facility Halo Lattice



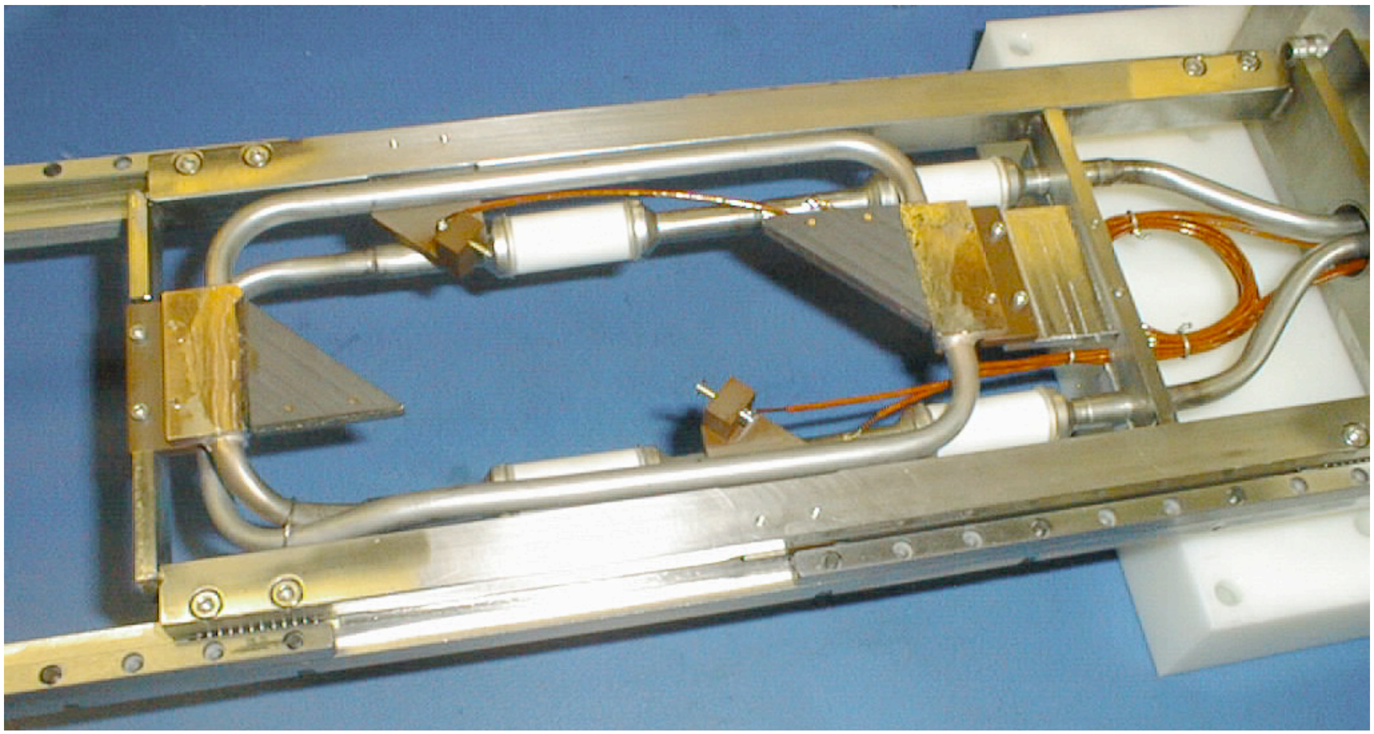
Wire scanner and halo scraper (WS/HS) profile instrument acquires beam projected distributions.

- Horizontal and vertical projected distributions measured at each "station"
- Wire scanner: 33-μm C fiber measures distribution core
  - Protons not stopped in fiber (range in C: 0.3 mm)
  - Fiber biased to optimize secondary electron (S. E.) emission (S. E. leaving the fiber detected)
  - S.E. yield measured to be ~ 47% for 6.7-MeV protons on the C fiber.
- Scraper: Graphite brazed on Cu scraper measures projected distribution tails
  - Range out protons in 1.5-mm thick of graphite
  - Scraper biased to inhibit S.E. (protons deposited in the scraper detected)
  - Graphite/Cu scraper water cooled to reduce average temperature



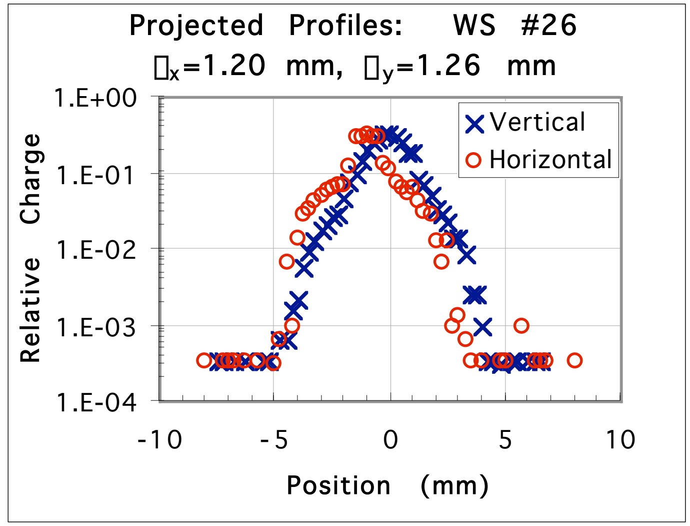


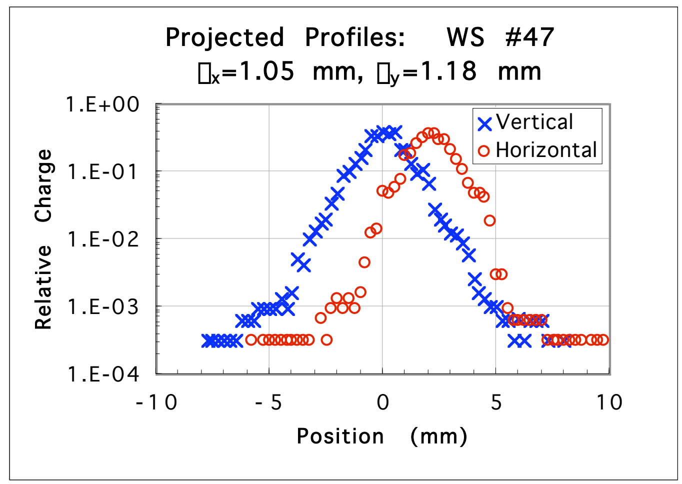
Close-Up of the Movable Frame of the Halo WS/HS Assembly



Typical Wire Scanner Data: WS #26 and #47

- Typical 6.7-MeV beam parameters during profile acquisition
  - Repetition rate: 1 Hz
  - Pulse length: 30 μs
    - Short pulse lengths achieved using RFQ blanking technique
  - Peak beam current: 100 mA
- Distribution dynamic range: typically > 1000:1
- Pulse length limited by onset of thermionic electron emission
- Typically acquired accumulated charge data in the last 10 to 20 μs of the pulse.
- Only one axis fiber in beam at any time
  - Other WS and HS are outside beam pipe aperture
- Rms width repeatability:
  - Instrumentation precision and beam variations: ~ 0.04 mm





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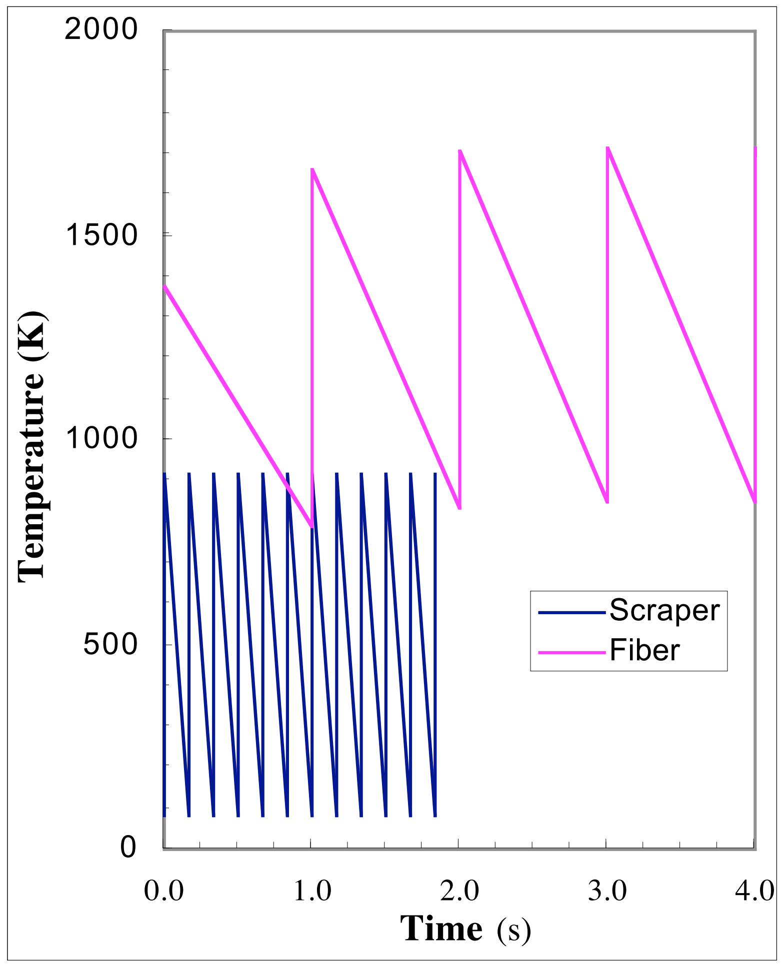
Wire and Scraper Thermal Limitations

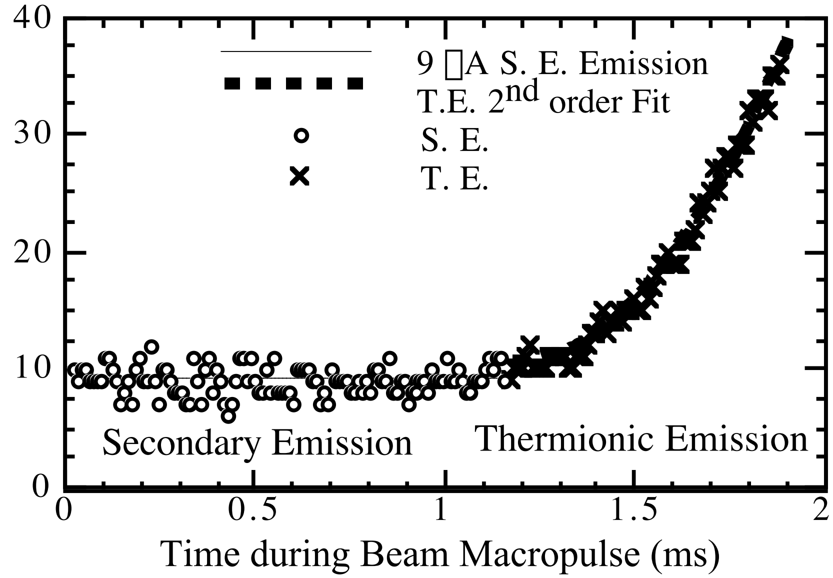
- Both the scraper and wire were designed to be limited to 1800 to 2000K.
  - Primary reason: limit thermionic emission
- Wire temperature simulation shows limiting 1800K temperature can be reached within approximately 30 s
  - 1 mm rms widths and 100 mA
  - Wire thermal model assumes little conduction and radiative cooling
  - No indication of any rf induced heating of wire from the modulated or bunched beam during experiment.
- Scraper thermal limitations:
  - Cannot insert scraper completely into beam core
  - Tradeoff: scraper insertion, duty factor, and current density.
  - To reach similar temperature limitations as wire, scraper is inserted to between 1.5 and 2 rms width point.



LEDA Wire-Scanner-Fiber Electron Emission

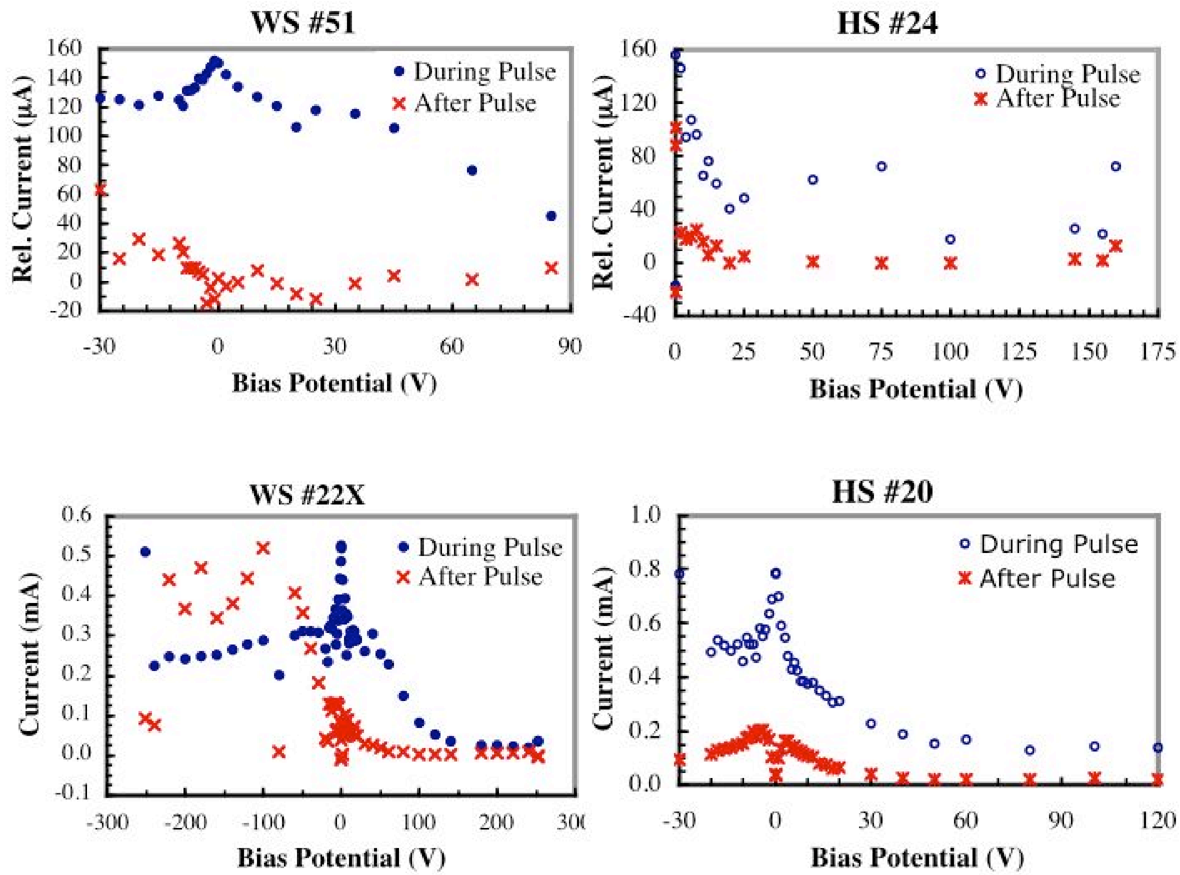
- Secondary emission (S.E.) is independent of both time and fiber temperature
  - Primary dependency: amount of energy deposited into a very thin outer layer of the fiber by beam (Sternglass model of secondary emission)
- Measured S.E.emission coefficient (0.1-mm SiC fiber, 6.7-MeV Protons): 50% to 60%

  Initial measurements of S.E. coefficient with the 33-μm C fiber: 40%to 50%
- Thermionic electron (T.E.) emission limitation
  - Characteristic temperature squared dependency after fiber has had time to heat up
  - For example, T.E. emission overcomes S.E. emission at 1.2 ms
  - Resulting in distortion of profile core distribution shape if WS data are acquired after onset of T.E.



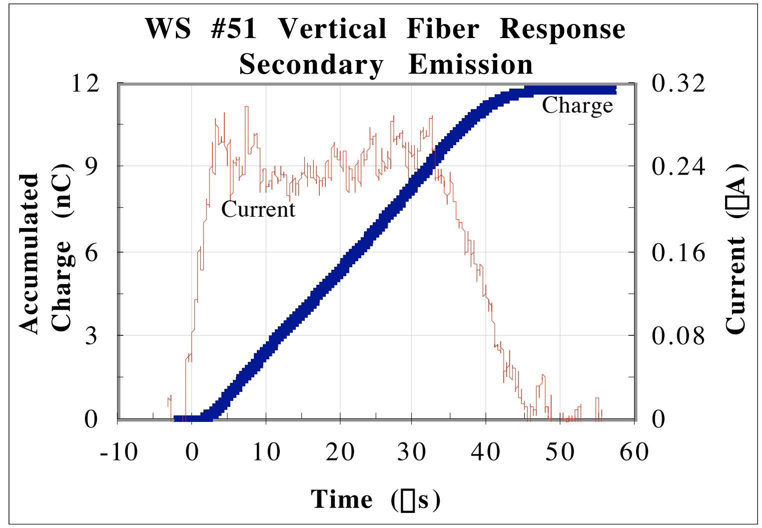
Wire Scanner and Halo Scraper: Bias Vs. Emission

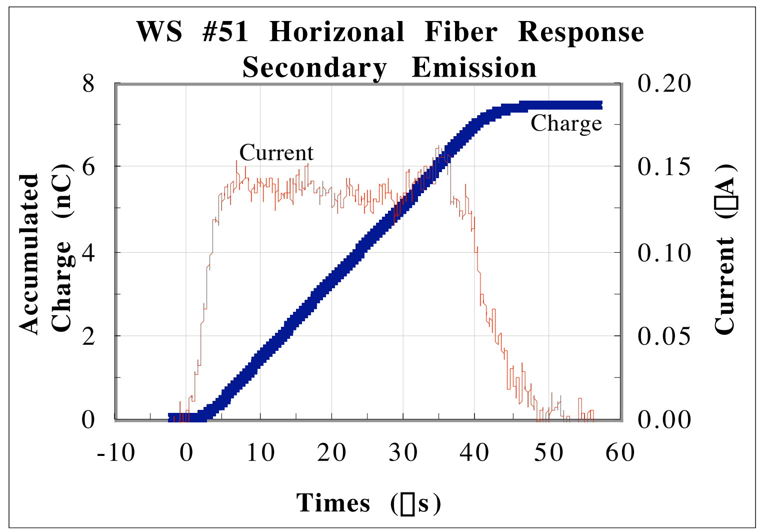
- Parked the wire in the beam core.
  - Scraper parked on core edge.
- Applied a variable bias potential
- Wire scanner optimum bias: -6 to -12 V (picked -12 V for data acquisition)
  - Unexpected 15% elevation in net current around 0 V bias
  - Increasing positive bias reduces secondary electron emission
    - +150V, S.E. current near zero
  - Larger negative bias increases positive ion attraction
- Scraper optimal bias: +20 to +40 V (picked +25 V for data acquisition)
  - Elevated net current near 0 V
  - S. E. almost entirely inhibited by +20 V



Details of WS Charge Accumulation and Beam Current Pulse Generation

- RFQ blanking
  - 75-keV source beam is injected into the unpowered RFQ
  - RFQ power is quickly turned on
  - After 30-μs, injector is turned off
- Charge is accumulated in the first stage of the detection electronics - a lossy integrator
  - Integrator reset time constant: 1 ms
  - Scraper has a separate channel of the same detection electronics
- Pictures show typical time based waveform of digitized WS signal and its integral.





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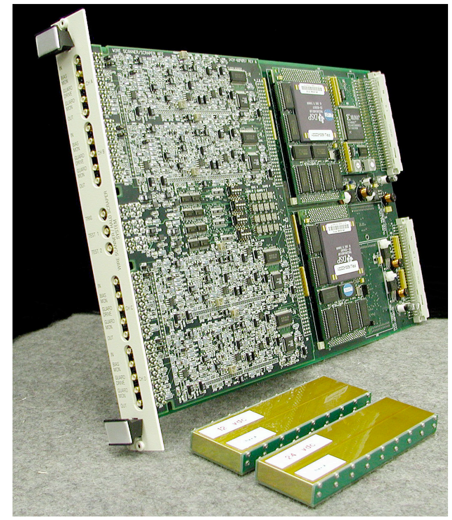
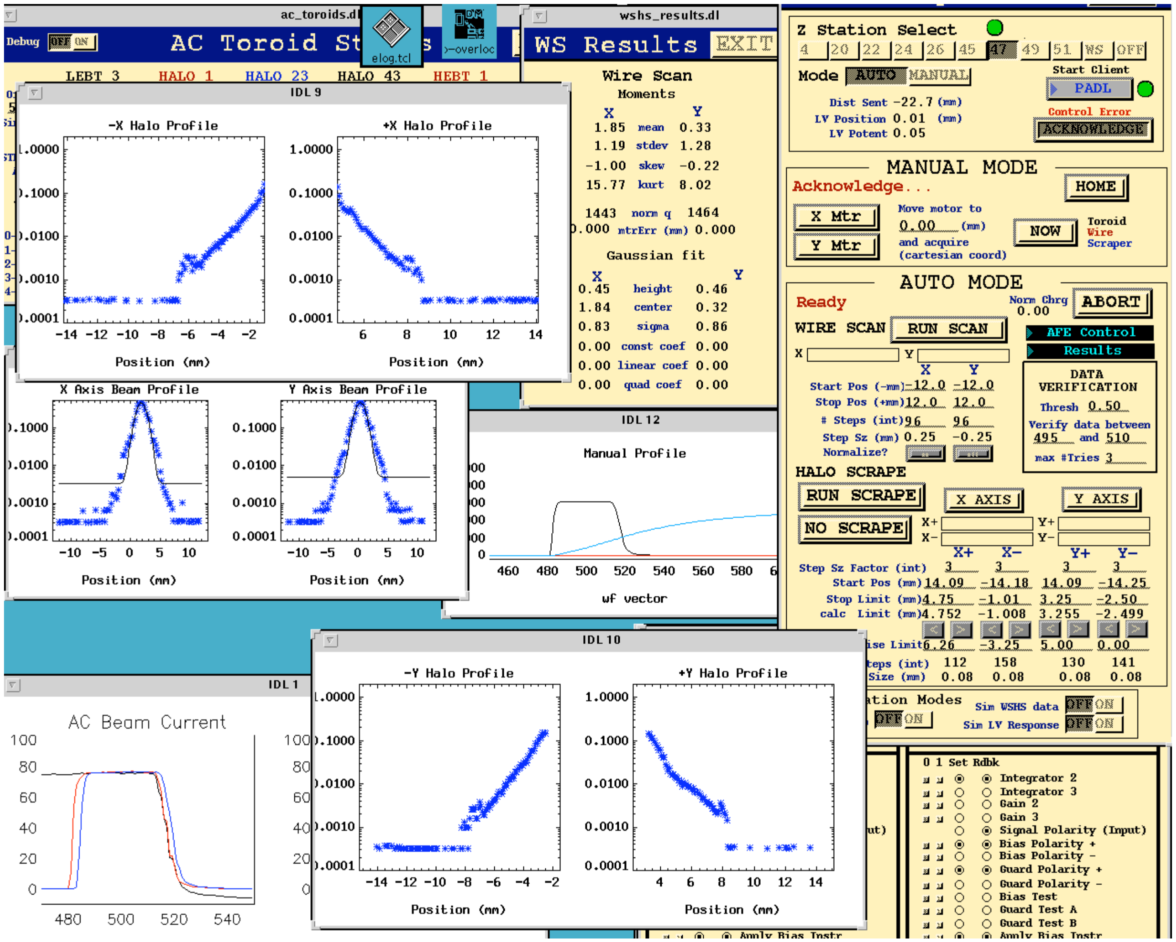
Detection Electronics and Wire/Scraper Movement Control Details

- Electronics integrate S. E. or proton current
  - Lossy integrator followed by gain stage
    - Reset time constant 1 ms
  - Accumulated charge is digitized with a 12 and 14 bit digitizer at a 1 MS/s rate.
  - Acquire accumulated charge difference by digitizing and subtracting 2 samples per waveform
  - 4 capacitances and gain choice
    - No switching within a scan or scrape
    - Range: 1.3 μC to 0.15 pC
  - Measured analog equivalent noise at maximum gain: 0.03 pC
  - LSB of 14 bit digitizer at max gain: 0.15 pC
- Wire/Scraper movement control performed by off-the-shelf products
  - National Instruments digital controller
  - Compumotor Gemini electronic drivers
  - Compumotor OS-22B stepper motors
  - Dynamics Research Corp. linear encoder, (5 μm resolution)
  - Measured wire placement error: < ± 0.02 mm or < ±2% rms beam width
  - Movement includes brake engagement and drive inhibit to reduce electrical noise



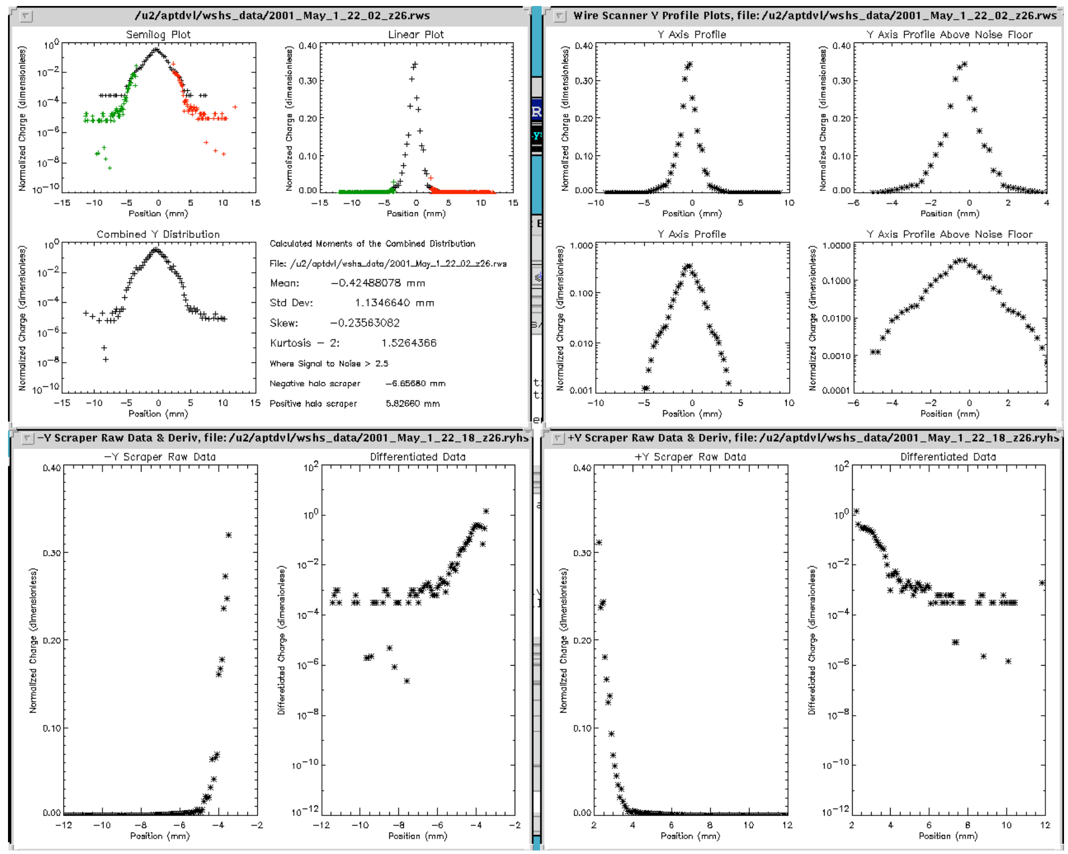
Example of EPICS Control and Operational Screens for the WS/HS Instrumentation

- EPICS control screen and sequence provides
  - –Operator GUI interface and overall control
  - –Instructs National Instruments, LabVIEW Virtual Instrument to move wire/Scraper
  - –Instructs Reseach Systems, Inc., Interactive Data Language (IDL) to perform analysis and data melding
  - –Acquires synchronous data from detection electronics and nearby toroids

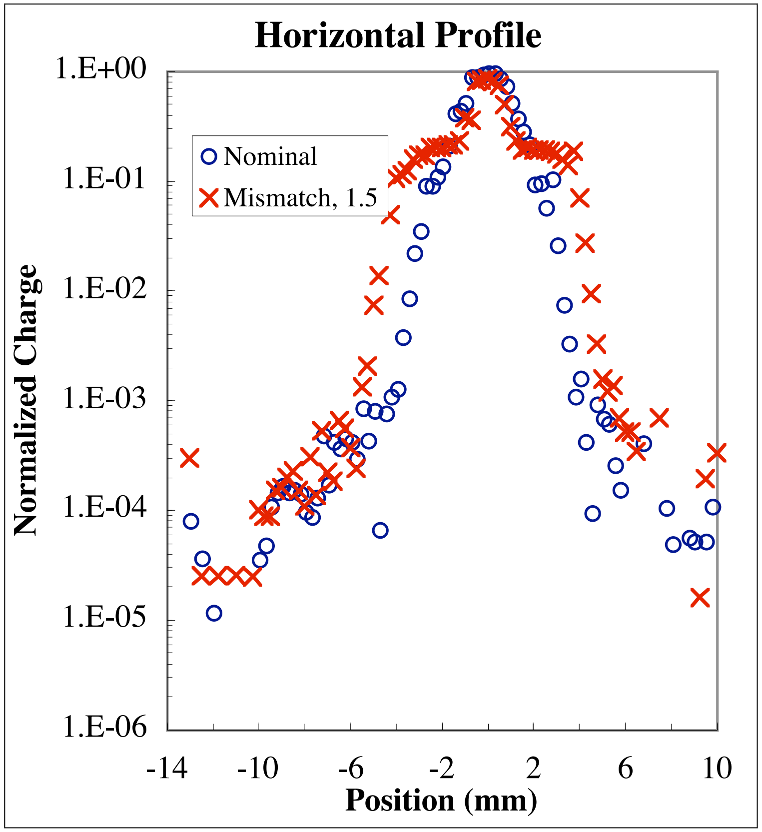


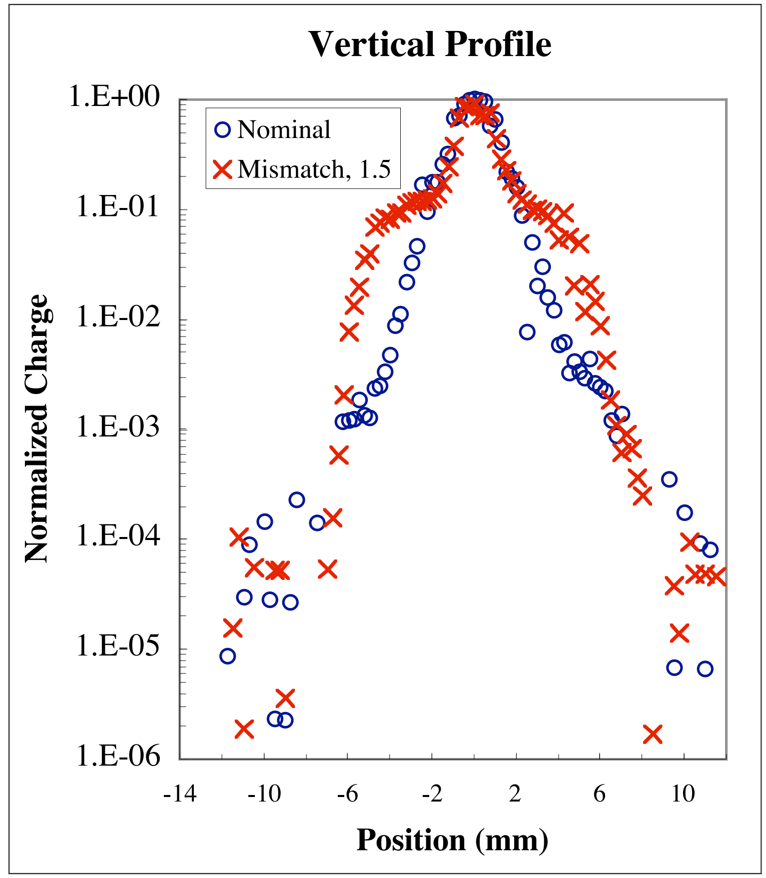
Online Method of Joining Wire Scanner and Halo Scraper Data Sets

- Meld the scraper and wire scanner data sets using IDL
  - –HS data is spatially differentiated
  - –Averaged over several points
  - –WS and HS charge data are normalized
    - Measured fiber and scraper edge distance correlates spatial data



Combined WS and HS Profile at Location #51: Spatially Differentiated, Averaged, etc.





"What we did right?"

- Used a wire and scraper to acquire the wide dynamic range profile measurement
  - Implies integration of differentiated scraper data with wire data
- Graphite/copper brazed joint for the scraper
- Detection of secondary electronics (WS) and stopped protons (HS)
  - Non-switched lossy integrator as first stage
  - Differentially acquired data greatly reduced background noise
- Motor type selection: stepper motor - No dithering
- Understanding the beam/wire and beam/scraper interaction
  - e.g., understanding the bias relationships
- Local PC IOC with LabVIEW running motor control
  - (We used a commercial-grade WinTEL platform but others are possible.)
- Provided real-time signals and calculated moments to operators.
  - Sufficient information to immediately judge data value.
  - Two types of data storage (partial processed and total raw).
- Used an external math software package for on-line and off-line data analysis.
  - Used IDL but MatLab or LabVIEW might have been equally good choices.
- Installed the stepper motor electronic drivers in rack area and NOT in tunnel.
  - Implies a bit more complicated cable plant but in the long run worth it during operation and troubleshooting phase.

Lessons Learned

- WS/HS Measurements
  - Improve the IDL/EPICS interface.
  - Choose a motor/electronics driver package that has a small dc hold current mode that is easier to configure.
    - This could allow faster data acquisition, which would allow further averaging in the acquisition and analysis.
  - Provide a better method of on-line testing/verification of the WS/HS - our planned signal injection method added too much capacitance to the input signal path.
  - Investigate a less expensive hardware standard than VXI that allows multiple WS/HS acquisition stations per single IOC computer.
  - Consider adding resolution to digitizer card - e.g., 16 bit ADC w/ 1 bit for sign.
  - Adding further automation to the data analysis.
- Consider installing a full 2-D emittance station near the end of the RFQ (e.g., slit and collector)
  - Reason for not installing it besides economics, slit design would not have allowed for full peak current, 100-mA, beams. Possibly few mA peak current.

Beam Halo Instrumentation Summary

- Primary beam core and halo distribution measurement instrumentation is a combination of a wide dynamic range wire scanner and halo scraper
  - Typical dynamic range: ~ 10^5:1
    - Combination wire and scraper allow this dynamic range
    - Wider dynamic range very useful to observe slight mismatched conditions
  - Total spatial error: < +/- 2% of the beam's rms width
  - Effective accumulated charge noise floor: < 0.15 pC
- Secondary electron yield was measured to be ~47% per incident proton
- Wire scanner bias optimized at -12 V
- Halo scraper bias optimized at +25 V
- Online analysis provides a summary of projected distributions by providing calculated moments, Gaussian fits, and "maximum extent"

Some Relevant Papers

- Halo Experiment Physics & Results
  - T. P. Wangler, et al., "Experimental Study of Proton-Beam Halo Induced by Beam Mismatch in LEDA," June, 2001, PAC 2001.
  - C. K. Allen, et al., "Beam Halo Measurements in High Current Proton Beams," Phys. Rev. Lett. 89, No. 21, (214802) 2002.
  - Ji Qiang., et al., "Macroparticle Simulation Studies of a Proton Beam Halo Experiment," Phys. Rev. ST Accel. Beams, 5, (124201), 2002.
- Halo Instrumentation
  - J. D. Gilpatrick, et al., "Experience With The Low Energy Demonstration Accelerator (LEDA) Halo Experiment Beam Instrumentation ," June, 2001, PAC 2001.
  - J. D. Gilpatrick, et al., "Beam-Profile Instrumentation For Beam-Halo Measurement: Overall Description And Operation," June, 2001, PAC 2001.
  - R. Valdiviez, et al., "The Final Mechanical Design, Fabrication, And Commissioning Of A Wire Scanner And Scraper Assembly For Halo-formation Measurements In A Proton Beam," June, 2001, PAC 2001.
  - M. Gruchalla, et al., "Beam Profile Wire-scanner/Halo-Scraper Sensor Analog Interface Electronics," June, 2001, PAC 2001.
  - J. Kamperschroer, et al., "Analysis Of Data From The LEDA Wire Scanner/Halo Scraper," June, 2001, PAC 2001.
  - J. D. Gilpatrick, et al., "Biasing Wire Scanners and Halo Scrapers for Measuring 6.7-MeV Proton-Beam Halo," May, 2002, BIW 2002.